CONSTRAINTS ON THE SHOCK AND THERMAL HISTORIES OF SOME COMPONENTS FROM THE UNIQUE CHONDRITE, ALLAN HILLS 85085, AND THEIR IMPLICATIONS. Adrian J. Brearley, Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131, USA.

Allan Hills 85085 is a unique chondrite whose physical and chemical properties differ in a number of important respects from all other known chondrite groups [1,2,3], although it appears to share some affinities with the CR group of carbonaceous chondrites [4]. Among the unusual characteristics of ALH 85085 are 1) an extremely high abundance of metal, 2) a significant volatile depletion, 3) the fine grain size of its constituent components and 4) a low abundance of intact chondrules. Fine-grained matrix is also extremely rare, a property which ALH 85085 shares with the enstatite chondrites. The unusual nature of ALH 85085 has led to some discussion as to whether this meteorite could have formed in the nebula or if later parent body processes were responsible for producing the unique combination of properties. Wasson [5] has argued that many of the features of ALH 85085 might be best explained by impact processes on a large parent asteroid. Bischoff *et al.* [6] have also suggested that impact processes have been important in the evolution of ALH 85085 and that the small glassy chondrules, similar to glassy spherules in the lunar regolith, are quenched impact melts. In contrast [1,2,3] have presented arguments that the constituents of ALH 85085 formed in the nebula, albeit by unusual processes, and suffered only minor secondary asteroidal processing. An understanding of the thermal and shock histories of the different components in ALH 85085 can potentially help discriminate between these two different models. Such information can be provided by the microstructures of silicate and metallic phases present in the diverse components, such as mineral and lithic fragments, matrix, etc. Some of these different components have been studied by transmission electron microscope techniques in an attempt to elucidate their thermal and shock histories.

General microstructure. TEM observations show that an ultrafine-grained matrix ($<1 \mu m$) is present, interstitial to the optically observable fine grained silicate and metal components. This matrix consists largely of angular fragments of olivines, pyroxenes and Fe,Ni metal which range in size from 0.5 μm down to < 50 nm and occurs locally as layers up to 1.5 μm thick between clasts, although in most cases the clasts are in direct contact. An interstitial melt phase, suggested by [6] has not been observed. These angular fragments probably formed by cataclasis and fragmentation of larger silicate fragments, probably during brecciation on the parent body.

Evidence for shock. The absence of interstitial melt between clasts in ALH 85085 indicates that the overall degree of shock experienced by this meteorite is low (<10 GPa). Apparently lithification did not occur as a result of impact produced shock melting along grain boundaries. However, individual components of ALH 85085 have been shocked as noted by [1,2]. Scott [1] and Grossman *et al.* [3] noted the presence of Neumann bands in many of the metal grains indicative of shock pressures <~12 GPa. TEM has shown that shock effects are uniformly developed in metal throughout the meteorite. Dislocation densities are very high and individual metal grains have developed subgrains and exhibit a mosaic or domain microstructure with individual domains being 50-200 nm in size. Shock effects are heterogeneously developed in olivine and pyroxene. Although many grains show little or no development of dislocations, adjacent crystals may be very highly shocked. Some olivine grains have high densities of straight [001] screw dislocations indicative of shock deformation at relatively high strain rates and low temperatures (600-800°C) [7], probably at shock pressures <7 GPa. In addition rare clasts occur, which consist of corroded irregular shaped olivine crystals, surrounded by narrow rims of melt. These aggregates were once a single crystal of olivine, which has undergone shock melting at ultrahigh pressures, probably in excess of 45GPa [7]. Clino lamellae and unit dislocations have developed in orthopyroxene indicative of shock pressures of the order of 16GPa. Locally pyroxene is extremely highly shocked and has developed a lamellar microstructure with a high dislocation and stacking fault density, like that observed in bronzite shocked to 22 GPa [8].

Chondrules and silicate clasts. The majority of silicate clasts have experienced extremely rapid cooling [1,2,3]. Many are microcrystalline, and fine-grained twinned clinopyroxene indicative of rapid cooling (>10000°C/hr) [9] is present in some clasts. However, a number of chondrule fragments have been observed which clearly have experienced comparatively extended cooling histories. Some chondrule fragments contain abundant orthopyroxene, indicative of extremely slow cooling (<1°C/hr) or extended high temperature annealing. A further clast contains coarse grained pigeonite ($En_{67}Fs_{30}Wo_3$) which contains thin exsolution lamellae of augite and antiphase domains (APBs) caused by the C2/c to $P2_1/C$ inversion at ~850°C with a domain size of ~0.4 μm. These microstructures constrain the cooling rate of this chondrule to ~1°C/hr [10].

Reduced clasts. Grossman *et al.* [3] reported fine-grained clasts (~400μm in size) in ALH 85085 which contain subrounded metal grains probably indicating solid state reduction. Two of these reduced clasts have been studied in detail and are clearly unusual objects with intriguing thermal histories. One clast consists of low-Ca pyroxene, anorthite and Fe,Ni metal and the second has the same assemblage plus olivine (Fo_{95}). The compositions of the low Ca pyroxene are similar in both clasts (En_{91-95}), but metal in the second clast is more Ni-rich (Ni = 9-13 wt% c.f. 5.5%) and compositionally more heterogeneous. The grain sizes of the silicate phases range from 200 nm up to > 1 μm and abundant 120° triple junctions between phases indicate a close approach to textural equilibrium, indicative of sintering over an extended period of time. Fe,Ni metal grains vary in size from < 50 nm up to > 1 μm, and occur as facetted to subrounded crystals. Metal has nucleated preferentially at triple junctions. These textures are consistent with reduction of an iron-rich silicate host as suggested by Grossman *et al.* [3]. Electron diffraction and HRTEM show that the low Ca pyroxene is almost entirely the orthorhombic polymorph with highly localized lamellae of intergrown clinopyroxene, which may be the result of shock. These microstructures indicate that the clasts must have been cooled slowly from high temperature (>1000°C) at <1°C/hr [9] down to temperatures of ~700°C [11].

Conclusions. The components of ALH 85085 exhibit diverse shock and thermal histories, typical of chondritic breccias. Although shock effects can be heterogeneously developed in meteorites, the wide range of degrees of shock found in ALH 85085 is difficult to reconcile with shocking of these components *in situ* after accretion. ALH 85085 appears to consist of components which have been shocked to different degrees prior to final lithification, like some lunar and meteoritic regolith breccias [12,13]. This may have occurred on the same parent body, but involved later admixing of these different components, possibly by regolith gardening. The thermal histories of components in ALH 85085 are clearly extremely unusual. It has already been noted that chondrules and silicate fragments which have been cooled extremely rapidly dominate in this meteorite [1,2,3]. This study shows that a significant fraction of the remaining silicates have experienced comparatively extended thermal histories, such that orthopyxroxene is the stable polymorph rather than clinopyroxene. Although orthopyroxene chondrules can occur in type 3 chondrites [14,15], they are generally rare and such chondrules are more typical of higher petrologic types (4-6). A further unusual feature of ALH 85085 is that silicates cooled at intermediate cooling rates (100-1000°C/hr) which are extremely common in unequilibrated chondrites, are very poorly represented. Thus the thermal histories of components in ALH 85085 appear to be bimodal in character, being dominated by rapid cooling (>10000°/hr), but with a significant number of clasts having experienced relatively slow cooling (<1°C/hr). These characteristics show that ALH 85085 is indeed a highly processed chondritic breccia [6] and cannot be regarded as a pristine chondrite which has been little affected by planetary processes. Although the mineralogical characteristics of the components in ALH 85085 are consistent with a nebula origin, the evidence of shock shows that their fine grain size is most likely to be the result of extended comminution of chondrules etc., on a parent body and not due to fragmentation and aerodynamic sorting in the nebula. Funded by NASA grant NAG 9-30 (Klaus Keil, P.I.).

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